# Air versus ground temperature data in the evaluation of frost weathering and ground freezing. Examples from the Romanian Carpathians

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**Abstract**: Air temperature is frequently used in frost weathering studies for the assessment of freeze-thaw cycle frequency and freezing intensity on different scales, although ground thermal behaviour is more relevant. In this paper we compare the estimations made by meteorological daily data with the results of continuous field measurements of air, soil and rock thermal regime in intra-mountain depressions, on mountain interfluves and steep rockwalls. The results show that air temperature alone can be used only as an indicator of diurnal freezing potential interval and of seasonal freezing duration, and is not a reliable proxy for assessing frost weathering magnitude, as it lacks the integration of ground cover by snow and of relevant topographic features like exposure and slope. For illustrating the depression units, which have the highest climatic potential of diurnal freezing (> 100 potential freeze-thaw days/year), we presented the case of Poiana Ştampei (the theoretical maximum freeze-thaw potential, 124 cycles/year, derived on air data), where only 2% of this interval corresponds to active freeze-thawing, while in the rest of the winter the ground is subject to snow-cover insulation. Moreover, the snow-free rock walls from those depressions record only 1/2 freeze-thaw cycles in comparison with the in situ air measurements, while only 35% of them are efficient (> 15 h°C per diurnal cycle). The ratio between active diurnal freezing, seasonal frost and snow cover interval modifies with altitude and is highly influenced by the degree of surface exposure. The high-altitude interfluves and plateau areas in the Bucegi Mountains show a much higher persistence of deep seasonal freezing due to a more unstable condition of snow cover and to constant low temperatures, while diurnal cycles keep a moderate frequency. The thermal regime in rockwalls highlights and documents the effect of direct solar radiation on exposed (snow-free) surfaces, with the clear distinction of diurnal and seasonal freezing on north and south-oriented steep slopes. Air is shown to be less sensitive than rock surfaces to opposite exposures and largely underestimates the diurnal freeze-thaw processes on the southern slopes. Direct solar radiation on the rock surfaces induces high amplitude diurnal oscillations which do not correspond to those of air, neither as frequency nor intensity. Nevertheless, air temperature derived indices are still relevant for the northern slopes directly connected to heat exchanges with the atmosphere. If snow cover duration proves to be the most important parameter to be included in frost weathering studies on typical horizontal surfaces (especially depressions and valley couloirs), the analysis of the thermal behaviour on mountainous rocky areas with various exposures and complex topography requires detailed ground temperature calibration of air values for good confidence results and estimations.

**Keywords**: air temperature, ground temperature, frost cycles, weathering, the Carpathians

## 1. Introduction

It is widely acknowledged that weathering by cryogenic action has a great contribution to the shaping of high altitude mountain environments (Goudie, 2004; Washburn, 1979; Williams and Smith, 2008). Both climatic and geomorphologic studies have attempted to evaluate and quantify the characteristics of frost processes and their impact on mountain surfaces, advancing monitoring approaches and investigation methods with increasing complexity and accuracy degrees. Although many classical studies use air temperature alone to make supposition on the very intensity of weathering, most of the recent works show that temperature is only one dimension of the process and even the general threshold of 0 °C may be misleading (Hall et al., 2012; Hall and Thorn, 2011; Matsuoka, 2001, 2008; Matsuoka and Murton, 2008). A thorough perception and large-scale modelling of thermal weathering intensity cannot be made without the unequivocal understanding of frost penetration mechanisms and ground thermal behaviour, which follow air tendencies, but may largely differ (Hall and André, 2001).

Laboratory experiments were made to evaluate the immediate effect of induced freezing in variable conditions, observing the volumetric changes and the occurrence of new joints and fractures (Washburn, 1979, Hallet et al., 1991). Nevertheless, the necessity of in-situ monitoring has lately been highlighted (Hall, 1999; Matsuoka, 2001; Sass, 2004, 2005; Amitrano et al., 2012) as field conditions (scale, control factors, climate) can hardly be reproduced in the laboratory. The development of new devices and data recording solutions has significantly eased the investigations in steep alpine areas. Thus, continuous measurements of ground (rock or soil) temperature and other parameters (water availability in rock, rock joints dynamics, snow cover, thermal conductivity and electrical resistivity of the ground surfaces) are now regularly performed in regional or country-level monitoring networks (Matsuoka 2008; Magnin et al., 2011; Gruber et al., 2004) at different spatial scales, the data being useful for more precise models and evaluations of climatic scenarios (PermaNET report) or modelling of rockfalls occurrence (Matsuoka and Sakai, 1999; Krautblatter et al., 2013).

In the context of these methodological developments and recent implications, it is more obvious that air temperature can be used at most as a proxy for frost weathering, because it cannot express the actual ground thermal behaviour but only the potential climatic conditions for frost occurrence (Hall and André, 2001). However, ground temperature data are available in a limited number of locations, thus for the purpose of large-scale studies (at mountain-range level) meteorological air temperature data are still to be used, with the existing limitations: the stations are frequently too widespread, the resolution of the data is poor and calibration with ground temperatures is not always possible. These issues can now be partially overcome by the use of multispectral and high resolution satellite images (Cheval et al., 2011; Bogdan, 2009).

The Romanian studies focusing directly on the problem of frost weathering are very few, most of the references using air temperature data available from the meteorological stations, of which only 11 are distributed within the periglacial belt (above 1800 m) of the Romanian Carpathians. Within these works, frost potential is presented for specific mountain valleys, sectors or massifs (Michalevici-Velcea, 1961; Urdea, 2000; Oprea, 2005; Nedelea, 2006; Andra, 2008). Special attention to surface temperatures is given by Stoenescu (1951) who performs in-situ measurements and describes in detail the seasonal frost in a high mountain area. Two contributions (Posea et al., 1974; Vespremeanu-Stroe et al., 2004) are dealing with the particular distribution of frost potential at the scale of the Romanian Carpathians at different altitudes, while only one study presents systematic ground temperature measurements in relation to freeze-thaw processes (Vespremeanu-Stroe and Vasile, 2010). Onaca (2013) also relates to this topic in discussing the periglacial processes in the Carpathians. Most of these give little weight to terrain properties, focusing solely on thermal data (which is the climatic forcing), without a wider perspective on "the real matter exposed to weathering", i.e. the ground surface characteristics. Thus, we consider that if there is no surface exposed to the action of frost, than the analysis of freeze-thaw weathering comes without any significant present implications for the modelling of landforms in such typical areas and locations.

Considering the scarcity of information on ground thermal regime in the Romanian Carpathians, our general purpose is to offer a reference on the local disparities between air temperature recordings and ground thermal regime based on field data. The main objectives are: i) to evaluate the potential of frost occurrence from air temperature data given by meteorological stations in comparison with simultaneous field ground surface temperatures, ii) to discriminate between in-situ air and ground temperatures relevance with the integration of topographical aspects and surface properties and iii) to assess whether or not is possible to calibrate air data with rock or soil temperatures or other climatic parameters in specific-scale locations and increase its reliability in expressing frost weathering.

This paper is part of a larger study dedicated to multiple aspects of frost processes and their implications in frost weathering in this mountain area based on extensive field monitoring in the last six years.

## 2. Study sites and methods

Air, soil and rock temperatures were recorded for one to several years between 2008 and 2013, with the use of automatic iButton thermistors (accuracy ±0.5 °C) set up at a two hours sampling interval. Measurement depth in rockwalls was 3 cm, while in soil the sensors were placed at 3 cm and 13 cm. Data from the meteorological stations Vf. Omu (Bucegi Mountains, 2504 m a.s.l.), Babele (Bucegi Mountains, 2206 m) and Țarcu (2180 m, Țarcu Mountains) were computed. In-situ air temperatures were also retrieved by the external sensors of RisfoxMini crack extensometers, which measured temperature every 30 minutes.

The locations were set in intra-mountain depressions and valley couloirs between 600 and 1300 m (Poiana Ştampei, Bixad, Joseni), mean-high altitude mountain interfluves and plateaus between 1100 and 2200 m (Sf. Ana Lake, Clăbucetul Taurului, Piatra Mare and Cocora Mountains, Baba Mare) and in steep rockwalls above 2200 m in Bucegi and Retezat Mountains on southern, eastern and northern exposures. As the intra-mountain depressions and high-altitude mountains were previously shown to have the highest number of potential frost days based on meteorological air temperature long-term records (Vespremeanu-Stroe et al., 2004), we reported to this study to test its estimations in natural field conditions. The detailed results from three study areas are discussed (Fig. 1) and the characteristics of the locations in each unit are presented as follows.

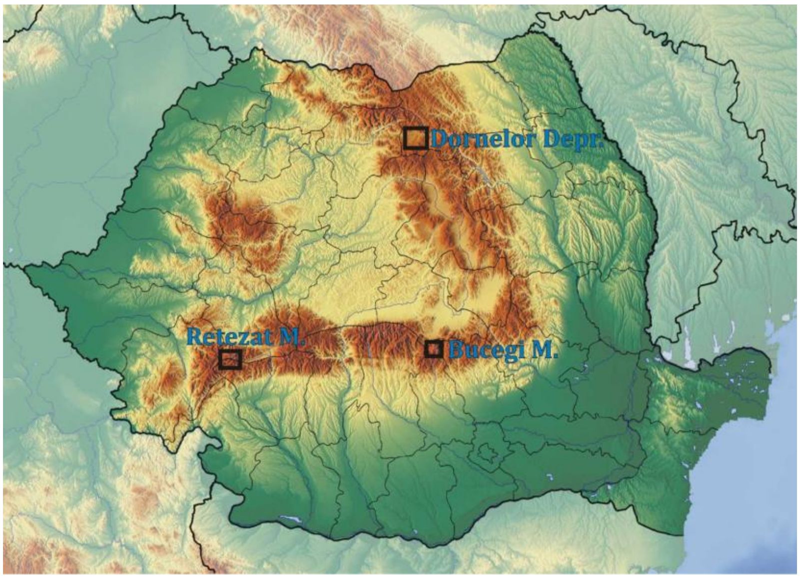



*Fig. 1.* **Main study areas position in the Romanian Carpathians: Dornelor Depression (Poiana Ştampei) in the Eastern Carpathians, Bucegi Mountains (Vf. Omu, Baba Mare, Cocora Mountain, Doamnei Valley) and Retezat Mountains (Turnul Porții) in the Southern Carpathians.**

a) Dornelor Depression is situated in the Eastern Carpathians, presents a mean altitude of 750-800 m and it is bordered by Suhard Mountains in North, Rarău Mountains in North-East and Călimani Mountains towards South. Its lithology is dominated by crystalline schist and volcanic rocks. Mean annual air temperatures range around 5 °C and precipitations cummulate 800 mm/year. This depressionary unit presents the longest period with frost occurence potential from Romanian Carpathians (Vespremeanu-Stroe et al., 2004; Posea et al., 1974), under the specific influence of frequent thermal inversion phenomena. In Poiana Ştampei location, sensors were set up in soil, on an andesitic outcrop and in air, during 2009-2010 at an altitude of 900 m.

b) In Bucegi Mountains, measurements were set near Vf. Omu peak (soil and rock, 2503 m), on the plateau near Baba Mare (soil and rock, 2263 m) and Cocora Mountain (soil, 2043 m, Photo 1) and in the upper part of Doamnei Valley (rock and air, 1929 m). All the sensors measuring soil temperature and the one measuring rock temperature at Vf. Omu were placed on horizontal surfaces, without obstacles around that would impose shadow effects. At Baba Mare (Photo 2) and Doamnei Valley the sensors were measuring temperature of vertical rockwalls (85-90° slope), exposed southward.

The investigated slopes were limestone outcrops, with medium porosity, which theoretically allows water infiltration at pores level, leading to ice segregation (Matsuoka, 2001; Hales et al., 2011). Multiannual meteorological data indicate mean annual temperatures of -2.4 °C at Vf. Omu (1960-2007) and average precipitation of 1500 mm/year.

c) The location investigated in Retezat Mountains was on Turnul Porții, where air and rock temperatures were registered in a north-exposed vertical rockwall (2113 m a.s.l.). As the location lays on granite and granodiorite rocks, with high macrogelivation potential (Urdea, 2000), there is a visible high frequency of deep joints sets which it is assumed to enhance the detachment of medium and large size boulders.

*Photo 1-2:* **Examples of ground temperature monitoring locations in Bucegi Mts: Cocora Mountain interfluve (top), Baba Mare rock outcrop (bottom).**

By selecting these locations, we try to present the behaviour of the ground surfaces with long-lasting snow cover (flat surfaces) and of those surfaces which are at least in part snow-free, due to steep topography and wind action (i.e. the vertical rock slopes). The data from additional locations were used to infer the ratio between the days with snow cover and those with freeze-thaw cycles during the winter season, as well as the difference between oppositely oriented rockwalls.

## 3. Results

In relation to frost weathering, freeze-thaw cycles may be regarded as both preparing and triggering processes, but in any case their evaluation is based on frequency and magnitude, which enable us to differentiate between diurnal (shallow and small depth) and seasonal (deep freezing) cycles. In the same time, it has been shown that, depending on ground properties, the temperature at which water freezes in rock or soil may vary significantly. Based on the existing models (Matsuoka, 2001; Washburn, 1979), in our previous study we considered a threshold of 12 h°C (hours degrees) for a cycle to be efficient (Vespremeanu-Stroe and Vasile, 2010), and the short oscillations through 0 °C have only a shallow effect which makes them inefficient in promoting intense damage upon ground surfaces. It is obvious that this filter might be reviewed and completed, and we are aware that without clear knowledge of water content and dynamics in subsurface, even ground temperature can only provide a potential condition for frost to occur. Keeping this in mind, we here use the 0 °C threshold to get a good comparison with the air data, for which a better limit than this one is difficult to establish. Further, different situations are described in order to distinguish between the signals offered by air and ground temperature.

### *3.1. Poiana Ştampei location*

The temperature data available in the meteorological archives cover only daily values of mean, maximum and minimum air temperature. On this basis, the formula presented in our reference study (Vespremeanu-Stroe et al., 2004) uses these parameters, gives the number of days with freeze-thaw occurrence potential (Ng) and refers only to diurnal oscillations:

*Ng = N(Tmin) - N(Tmax)*, where *N(Tmin)* = the number of days with the minimum temperature ≤ 0 °C and *N(Tmax)* = the number of days with the maximum temperature < 0 °C. The result indicates a number of 124 days with frost cycle potential per year at Poiana Ştampei, reporting to the 1961-1990 time-sequence of air values.

For the interval July 2009 - July 2010, our data indicates 97 diurnal oscillations through 0 °C in the air temperature series (Fig. 2), which fits with the meteorological multiannual value standard deviation. During winter, air shows the lowest value (-21 °C), followed by the rock surface (-16 °C) which shows the same variations but much smaller amplitudes, while in soil during the entire season temperatures are close to 0 °C, with no significant oscillations (Table 1). This clearly indicates the presence of an isolating snow layer, which makes the soil to remain at the limit of freezing, without connection to the air fluctuations.

The investigated rock outcrop, which was permanently snow-free as shown by the data (Fig. 2), exhibits 44 cycles, less than half of those counted using the air temperatures (Table 1). Using the 12 °C freezing index as a threshold, 35% of these cycles in rock are actually efficient. This difference shows a more realistic dimension of the process, because it relates the temperature to the surface exposed to weathering and its thermal properties. Our presumption is that the air cycles with reduced amplitude (less that 1.5 °C, for instance) do not materialize into rock cycles, because of the energy modifications during phase change. Therefore, air temperature itself largely overestimates the frequency of frost processes (44 cycles instead of 97) and this may change the presumed intensity and efficiency of gelivation and gelifraction in this specific morpho-climatic units.

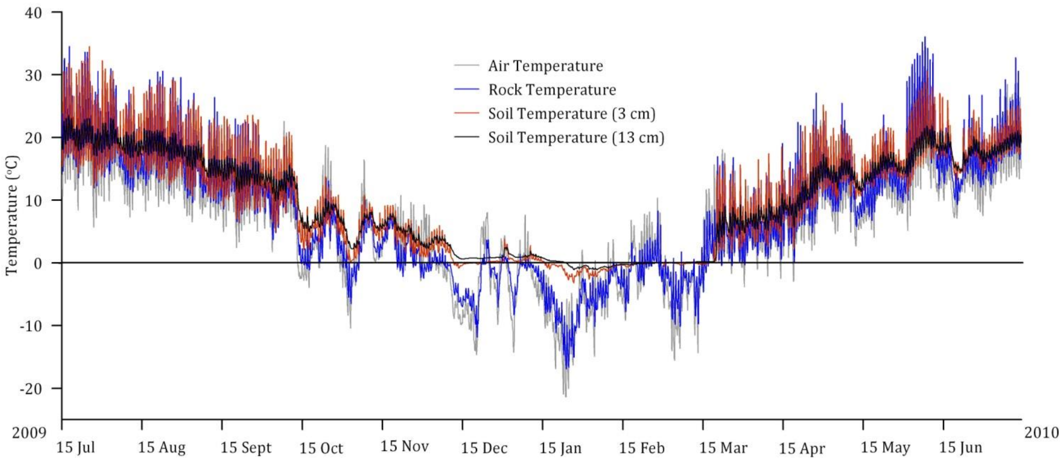



*Fig. 2* **Air versus ground (soil and rock) thermal regime at Poiana Ştampei location, Dornelor Depression (July 2009 - July 2010; recordings time step of two hours).**

Given the morphometric characteristics of Dornelor Depression (low-mean altitude, predominance of flat surfaces, forested slopes) and the results presented above, we could further assume that frost weathering does not have a significant contribution to the present modelling of the relief, although there is a great climatic potential, because most of the ground is covered by snow and the efficient diurnal cycles are less than 10% of the air temperature derived frost cycles. The soil temperature data show that for three months, horizontal surfaces are insulated and get 0 °C equilibrium temperature of thick snow layer. Within the entire frost potential interval given by the air thermal regime (13/10/2009-22/04/2010), there are only 7 oscillations through 0 °C at 3 cm depth and two at 13 cm, while the mean temperature is -1.7 °C and -0.5 °C respectively. This proportion is similar in the additional horizontal surfaces that we investigated and emphasizes the importance of snow cover in such studies. Figure 3B presents the number of days in which frost cycles may occur in comparison with the number of days with snow cover, as shown by two-year data in all the soil temperature monitoring locations. If the number of frost cycles shows a slight increase with altitude, most probably due to lower temperatures in transitional seasons and to snow redistribution, the maximum duration of snow cover matches the depression and mountain valley units (e.g. Poiana Ştampei in Dornelor Depression – 133 days, Coteanu location on the Ialomița Valley, Bucegi Mountains – 145 days). Consequently, although presenting a high potential for frost weathering, these units are affected most of the winter by snow cover, due to typical shelter conditions and frequent thermal inversions, comparing to the mean-high altitude interfluves which are more exposed (Baba Mare – 69 days; Cocora – 64 days). There is a very reduced number of efficient cycles that affect horizontal surfaces in depressions (5 to 15 cycles, Fig. 3), which cover approximately 3 to 7 % of the total frost-potential interval defined by air temperature. Nevertheless, a high frequency of diurnal freeze-thaw may be attributed to the steep surfaces in river-cut gorges and defiles, which we did not documented here, but which generally cover a small percentage of the surface of intra-mountain Carpathian area.

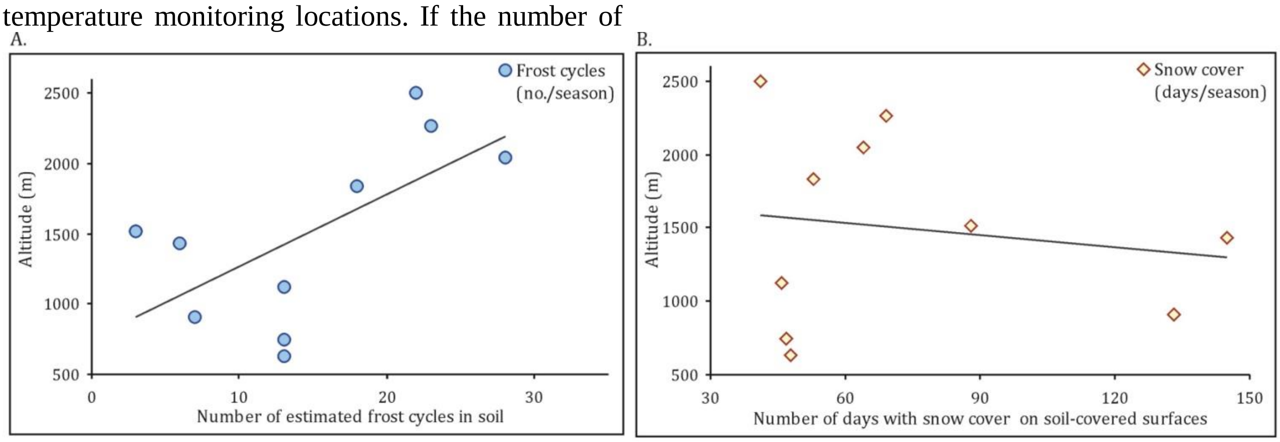



*Fig. 3.* **Efficient diurnal frost cycles (A) and days with snow cover (B) within the interval with frost occurrence potential. The graph is based on two years of soil temperature data in intra-mountain depressions and mean-high altitude mountain interfluves (2008-2010).**

*Table 1:* **Mean annual temperature and the number of frost cycles from in-situ continuous measurements in air, soil and rock at the selected locations (*sensors functioned from December to August exposed South; **sensors functioned from November to September exposed North, meteorological data from Țarcu station were used).**

| Location | Landforms | Alt. (m) | Meteorologic air data | | In-situ measured mean annual temperature | | | Number of diurnal frost cycles | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Diurnal cycles | Mean annual | Air | Rock | Soil 3cm | Air | Rock | Soil 3cm |
| Poiana Ștampei | depression | 900 | 124 | 5 | 6.8 | 7.5 | 9.5 | 97 | 44 | 7 |
| Vf. Omu | high alt. Interfluve | 2500 | 104 | -2.4 | - | 1.3 | 1.2 | - | 80 | 22 |
| Baba Mare | high alt. plateau and rockwall | 2200 | 96 | 0.1 | - | 4.2 | 3.3 | - | 130 | 23 |
| Doamnei* | rockwall | 1900 | - | - | 4.6 | 5.5 | - | 41 | 84 | - |
| Turnul Porții** | rockwall | 2200 | 81 | -0.6 | 0.4 | 0.6 | - | 21 | 24 | - |

### *3.2. Ground and air thermal regime at high altitudes in Bucegi Mountains*

The locations chosen at high altitudes (~ 2500 m), close to Vf. Omu peak, are facing a large variability of surface conditions, as a consequence of intense wind (average speed of 10-11 m/s in November-March, Vespremeanu-Stroe et al., 2012) which highly impacts the deposition of snow and ground-air connection during potential frost intervals, and overlays the severe thermal conditions at this altitude (mean annual air temperature of -2.4 °C). To evaluate the interval of potential frost occurring, we considered the daily air temperature data from the meteorological record as a proxy, as shown in the Poiana Ștampei case. In this context, soil temperature data at 3 cm depth shows that at Vf. Omu, during 70% of the duration of frost potential interval, flat soil surfaces are covered by snow (Fig. 4A). Complementary, the remaining 30% of the days are affected by diurnal freeze-thaw cycles. The ratio of freezing to snow-covered intervals (30/70) defines the temporal availability of flat surfaces from a location to the manifestation of gelivation processes. As this ratio was 2/98 (2% diurnal freeze-thaw of the ground, to 98% - snow cover effect) in the previous cases from intra-mountain depressions, it is noticeable that changing the altitudes, but especially the landform features, the ground thermal regime changes significantly, and the freeze-thaw cycles frequency as well.

The monitored rock surface at Vf. Omu location (Fig. 4A) was horizontal within the same topographic context as the soil location nearby. The number of diurnal freeze-thaw oscillations surpasses the one estimated in the air via meteorological records (80 frost cycles in rock *versus* 70 cycles in air, respectively). This can be explained by the higher thermal amplitude of uncovered rock surfaces which are exposed to direct solar radiation. On the other hand, during the monitoring period, a large interval (16 November - 31 March) faced the seasonal (or siberian) frost cycle with a mean temperature of -7 °C. During the first half of this interval, the rock followed the air temperature fluctuations, while in the second, diurnal amplitudes were much diminished, indicating the probable formation of an ice crust (layer) which prevents direct heating during sunny daytime. The ice layer still allows a filtered heat exchange with the atmosphere, as temperatures remain constant much below the freezing point and close by the mean air temperatures. The seasonal freezing appears in the same period at the soil locations from Vf. Omu and Baba Mare. Its intensity and duration recommend it as a major morphodynamic agent, as it deeply affects the ground with significant implications in weathering. If the interval with potential of diurnal freeze-thaw was given by the formula presented above, the duration of seasonal frost coincides with a more or less continuous period of winter days (Tmax < 0 °C) and should be used as well in evaluating frost weathering at a specific location, in order to get a full image of its action.

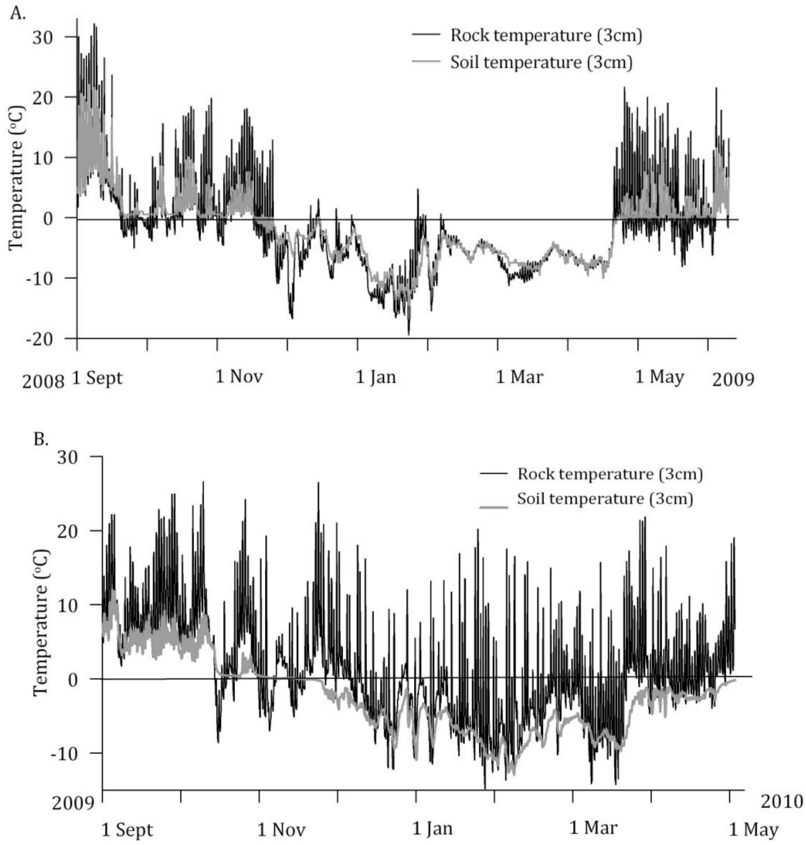



*Fig. 4* **(A) Thermal regime at Vf. Omu (2503 m) in horizontal rock outcrop and soil, during the cold season 2008-2009; (B) Thermal regime at Baba Mare location (2200 m) in vertical south-exposed rock slope and in soil during the cold season 2009-2010.**

Thermal behaviour of snow-free rockwalls was monitored on south exposed sites, besides the air and soil surfaces. The air and rock sensors set at Doamnei Valley location (1929 m) functioned from December 2011 to August 2012. During this period, the frost potential obtained from daily air temperature values (Vf. Omu meteorological station) is 39 days, very similar to the number of air diurnal cycles measured on site, 40 cycles respectively. There are twice as many oscillations observed in the south-exposed rockwalls (84 freeze-thaw cycles) in the same period, with significantly high amplitudes (Fig. 5) presenting an average freezing index of 35 h°C (hours degrees) for the diurnal freeze-thaw cycles, that imply a very high weathering potential of the rockwall at shallow depths (20 – 50 cm). The rock is on average 1 °C warmer than the air, which indicates again that rocky surfaces are largely influenced by the direct incoming solar radiation. These results give us a first sight of the exposure implications in the context of site-specific assessment of weathering intensity at different scales.

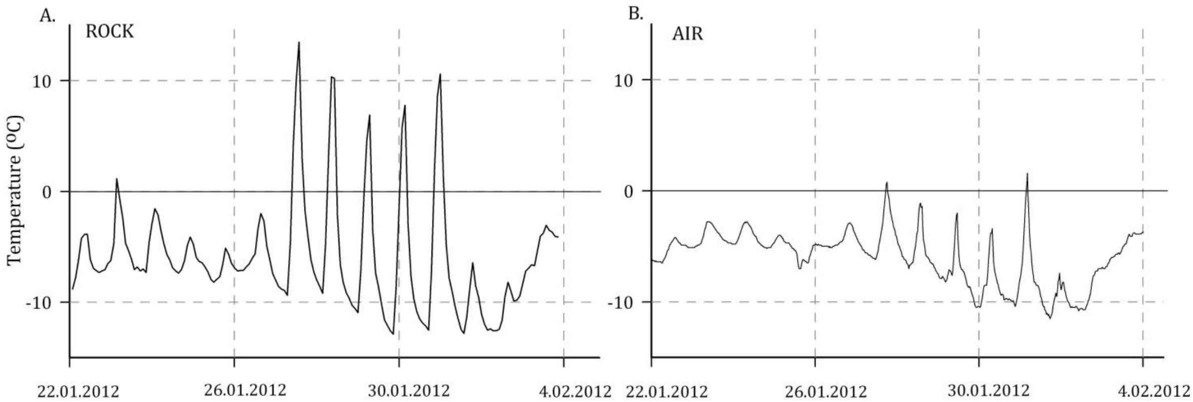


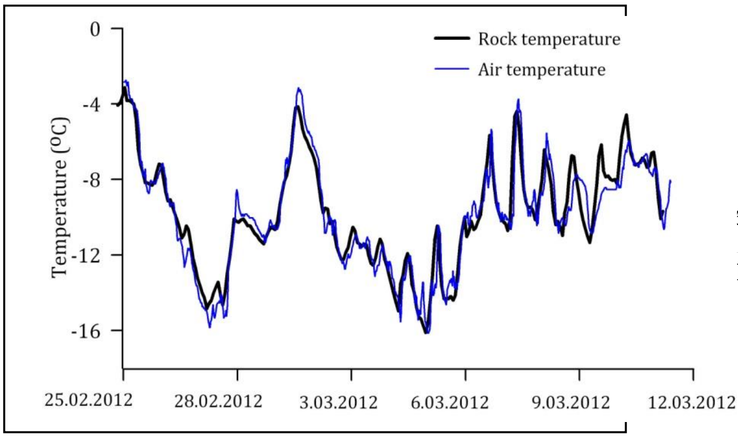

*Fig. 5.* **The co-evolution of temperature in the vertical rockwall exposed to south (A) and in air (B) at Doamnei Valley location in Bucegi Mts (1920 m) during 22 January - 4 February 2012 interval**

The difference between flat surfaces and steep rockwalls is presented in the data from Baba Mare location (2200 m) by comparing soil and rock temperature (Fig. 4b). This case also highlights the specific conditions of south-oriented surfaces, where 130 diurnal freeze-thaw oscillations occurred in one season (with a mean freezing index of 52 h°C for the diurnal freeze-thaw cycles), compared with the potential number of 69 cycles estimated based on daily air values, while seasonal frost is apparently missing in the very shallow rock layer, due to the intense solar radiation; conversely, the seasonal frost acts at depths of 0.2 – 2.8 m (according to modified Berggren equation). In opposite, the soil covered surface was dominated by the snow covered interval (58 days) and seasonal frost (120 days) and it exhibits a diminished frequency of diurnal oscillations (22 cycles) characterized by low intensity (freezing index equals 2-7 h°C).

### 3.3. *Rockwall thermal behavior at Turnul Porții site*

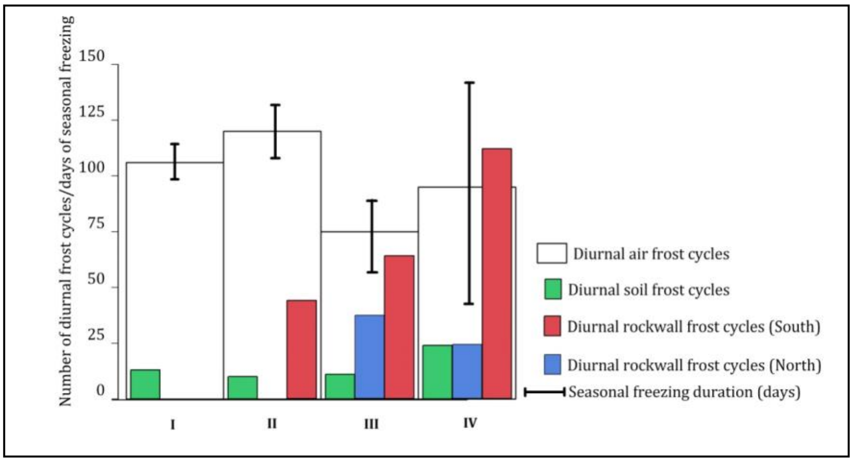
The air and rock sensors from Turnul Porții location (Retezat Mountains, 2130 m) functioned between 11 November 2011 and 1 September 2012. The rock sensor was set on a north-facing vertical slope and was snow-free except for the interval 5 December 2011 – 23 January 2012, when a very thin snow layer was probably present. The effect of direct solar radiation was clearly absent as the rock kept a similar temperature as the air during the 10 month period (average of 0.6 °C in rock, and 0.4 °C in air) and the number of diurnal cycles is similar (24 cycles and 21, respectively) (Fig. 6). Although these series do not cover an entire year, we can notice the large difference in respect to the multiannual air estimations at the same altitude, based on the nearest meteorological station (81 freeze-thaw potential days at Țarcu station, 2180 m). Thus, except for the ground temperature, air thermal behaviour seems also to be influenced by the northern exposure, but this study cannot give sufficient arguments on this problem.

Seasonal freezing has a significantly long duration on this site, and the mean temperature of this interval is -7 °C, favouring an intense and prolonged action to a potential depth of 7.5 m. The implications of this regime are reflected by the large dimensions of resulting rock fragments. Nevertheless, it is worth noticing the different manifestation of south and north-exposed rock surfaces which cannot be captured by the data gathered on a random meteorological station.




**6. The co-evolution of air and rock temperature at Porții north-exposed slope during 25 February – 12 h 2012 interval, under seasonal freezing conditions**

*Fig. 7.* **Annual distribution of diurnal freeze-thaw cycle frequency and seasonal frost duration in the investigated mountain units: I) low-altitude depressions and valley couloirs (300–700 m); II) high altitude depressions (700–1300); III) low to mean altitude interfluves and plateaus (1300-2000 m), IV) high-altitude interfluves and rockwalls (> 2000 m). Frost cycles number was calculated by measured air values, soil and rock temperature measured at 3 cm depth, on south and north-exposed vertical slopes and seasonal freezing from soil thermal regime.**



## 4. Discussion and Conclusions

Following the in-situ measurements results, it seems that air temperature can be used with reasonable confidence only to estimate the interval for diurnal freeze-thaw cycles occurrence and the seasonal frost duration. The use of air temperature data was found unsuccessful to determine the frequency and the efficiency of the freeze-thaw cycles in different ground types (soil and rock surfaces) based on their intensity (magnitude and duration), especially when remote locations (as usually the meteorological stations) are used, excepting the case of northern rockwalls where feasible estimations are possible. By comparing the mean annual meteorological data with the air values registered in the field, good correspondence resulted in a first phase for both depressions and high-mountain environments, but caution is necessary especially when considering snow-covered areas or south-exposed surfaces with high income of direct solar radiation where the correlations become weaker.

The estimation of freeze-thaw frequency by air temperatures can lead to large inaccuracies when additional ground surface characteristics are not integrated. Using the example of Poiana Ştampei location and those of intra-mountain depressions and high-altitude interfluves in the Romanian Carpathians, it can be observed that at ground-level the potential interval for diurnal freeze-thaw occurrence is actually split up in three distinct intervals: diurnal cycles, seasonal frost and snow cover. The duration of each time-sequence is variable and is strictly controlled by the topographical parameters of the setting (slope, soil-covered or free rock surfaces, rockwalls with different orientations) and by altitude, which impose distinct climatic forcings (Fig. 3, Fig. 6). In the analysis of horizontal surfaces, the temporal ratio between active freezing and snow cover intervals is of a great importance for a reliable result, as it can vary substantially from 2-4 / 98-96 in the depressions (persistence and thickness of snow-cover) to 20-30 / 80-70 on the high-altitude mountain interfluves (surface exposed to severe wind conditions and constant low temperatures). Thus, although having the highest diurnal freezing potential interval, snow cover is clearly the dominant regime in the depressions, due to the fact that wind-protected horizontal surfaces are the most extended, while in the plateau area of Bucegi Mountains above 2000 m, the seasonal frost is active for 2-3 months.

In the case of mostly snow-free rock surfaces, the effect of exposure can lead to very different interpretations of weathering magnitude and mechanisms, especially when comparing north and south-oriented rock facets. Air is shown to be less sensitive than rock surfaces to opposite exposures and largely underestimates the diurnal freeze-thaw processes on the southern slopes acting on shallow depths of 15 – 50 cm (Fig. 5-7). The daily effect of direct solar radiation on the rock surfaces induces an intense activity of high amplitude diurnal oscillations which does not correspond to those of air. Nevertheless, air temperature derived indices are still relevant for the northern slopes which only receive caloric energy from the air, as showed at Turnul Porții location. The most important aspect of north/south distinction is the assessment of seasonal and diurnal freezing weight in the general frost weathering process.

Finally, the reliability of air temperature values highly depends on the purpose of the study and of the capacity of integrating specific characteristics of the surface, especially when confronting with high slopes of opposite orientations. In such cases, more detailed topographic information are needed to get a reliable estimation of the manifestation of the weathering processes and the conversion of meteorological data is complex and requires in-situ thermal data from multiple altitudes, exposures and slope conditions for calibration. Horizontal surfaces such as depressions and large plateau areas should be easier to address, because the data from meteorological stations can provide relative information for the seasonal freezing and active diurnal freezing interval, whereas ground surface thermal measurements are needed for the evaluation of the snow-cover effect and to model the freeze-thaw cycles efficiency.

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